

SP-F8 Transfer of Energy and Nutrients by Anadromous Fish Migrations*April 24June 3262, 2002***1.0 Introduction/Background**

~~The Oroville Facilities (including the Fish Barrier Dam, the Thermalito Diversion Dam, and Oroville Dam) continue to block the migrations of fall-run Pacific salmon ecology studies illustrate the importance of the anadromous salmonids in the transport of nutrients and organic matter to the freshwater aquatic ecosystems where they spawn. Preying and spring-run chinook salmon and steelhead to their historical spawning streams in the upper basin of the Feather River. Estimated average numbers that spawned upstream of the Oroville Facilities each year prior to construction are: 2,300 fall-run and 5,200 spring-run chinook salmon and 2,000 steelhead (R. Croaker, memo to DWR). Studies from a number of streams have shown that spawning, excretion and death of upstream migrating chinook salmon and steelhead enrich the nutrient and energy supply of the fish's spawning streams, thereby enhancing their productivity (Bilby et al. 2001; Gresh et al. 2000; Cederholm et al. 1999). Feeding scavenging by terrestrial organisms on the salmon and their salmonids, eggs, and carcasses result s in the enrichment of terrestrial habitats as well. The elimination of anadromous chinook salmon and steelhead from the upper basin removed a source of energy and nutrients, and potentially reduced the productivity of the basin's aquatic and terrestrial biological resources. The resident population of salmonids currently in the Lake Oroville impoundment is a potential source of nutrients. (Cederholm et al. 1999; Gresh et al., 2000; Bilby et al. 2001).~~

~~The construction of the Fish Barrier Dam, the Thermalito Diversion Dam, and Oroville Dam (herein collectively called the Oroville Facilities) inhibits the migration of chinook salmon and steelhead to the historical spawning grounds in the tributaries of the Feather River located upstream of Lake Oroville (also called the upstream tributaries). This results in the removal of the salmonids as a source of energy and nutrients in these habitats and potentially reduces the productivity of the aquatic and terrestrial ecosystems.~~

~~This study plan is designed to address the effects of the Oroville Facilities operations on the nutrient and organic matter transfers to the upstream tributaries. To this end, escapement estimates for the upstream tributaries will be developed based on two separate methodologies. First, historical escapement surveys for the upstream tributaries will be reviewed to provide estimates of the number of salmon contributing to the upstream transfer of nutrients and organic matter prior to the construction of the Oroville Facilities. Second, potential escapement estimates will be developed based on the current available salmonid spawning habitat in the upstream tributaries and spawning densities from the spawning grounds downstream of Lake Oroville. Neither escapement estimate is designed to definitively determine the nutrients lacking from the upstream tributaries, but instead is designed to provide a range of estimates and baseline information useful for facilitating a dialog regarding appropriate nutrient mitigation techniques for the upper tributary environments.~~

2.0 Study Objective

~~The main objective of this study is to assess the ongoing effect that the Oroville Project, by blocking chinook salmon and steelhead runs, has on the energy/nutrient conditions and biological resources of the North, Middle and South Forks and West Branch of the Feather River and their tributaries and associated terrestrial~~

ecosystems. The information developed by this study plan will establish tools to evaluate future potential operational scenarios and other protection, mitigation, and enhancement measures (PM&Es).

~~The objective of this study plan is to collect baseline information to evaluate the effect of ongoing to serve as a foundation for development and evaluation of future potential protection, mitigation, and enhancement measures (PM&Es). One specific suggested PM&E is mitigation for blockage of the upstream transfer of salmonid-derived nutrients and organic matter to the upstream tributaries. The resulting information will be used. This study plan is designed to establish tools to develop and evaluate potential future PM&Es, and therefore a review of historical salmonid runs in the upstream tributaries, the size of the inhibited potential salmonid spawning runs to the upstream tributaries, and published data regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning is necessary to provide the tools to determine whether this potential PM&E is potentially feasible or beneficial.~~

Individual task objectives include:

- Task 1: Document, review, and summarize the available literature regarding historical escapement of anadromous salmonids in the tributaries upstream of Lake Oroville;
- Task 2: Estimate the potential maximum escapement of salmonids given the existing habitat of the tributaries upstream of Lake Oroville;
- Task 3: Document, review, and summarize the existing literature regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning and the nutrient transfer strategies mitigation plan methodologies, results, and potential implementation issues from other investigations.

3.0 Relationship to Relicensing/Need for the Study

The potential loss of ecological productivity due to the nature of the change in salmonid runs is a potentially continuing impact of the project on biological resources. Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in an Application for License to the Federal Energy Regulatory Commission (FERC) for a major hydropower project, including a discussion of the fish, wildlife and botanical resources in the vicinity of the project. The discussion needs to identify the impacts of the project on those resources, including a description of any anticipated continuing impact associated with continued operation of the project.

Little is currently known about the productivity or nutrient status of the Feather River and its tributaries upstream of Lake Oroville. Results of water quality sampling indicate that the North, Middle and South forks of the Feather River have relatively low levels of potentially limiting nutrients such as phosphates and nitrates (California Department of Water Resources (DWR) 2001). It is not known how much nutrients and energy have been lost as a result of the elimination of the chinook salmon and steelhead runs, nor what the effect of such losses has been on resident fish and wildlife populations in the upper basin. To estimate the net loss of nutrients and energy, it is necessary to estimate not only the effect of eliminating the adult upstream migrations, but also the effect of eliminating smolt downstream migrations, which removed nutrients and energy from the basin.

Nutrient and energy transfers to the upper basin from Lake Oroville resulting from spawning runs by fish currently residing in the reservoir and from consumption of fish in the reservoir by terrestrial species may partially compensate for the losses resulting from the elimination of the anadromous spawning runs. However, little is known about the level or significance of such transfers.

4.0—Study Area

The geographic scope of this study includes the FERC project boundary waters and the tributaries upstream to the next natural or man-made barrier for migratory salmonids. The scope also includes lands upslope of these stream reaches and Lake Oroville. This study is needed because project facilities currently inhibit the upstream movement of anadromous fish stocks and may therefore potentially affect the transfer of fish-derived nutrients and organic matter to the tributaries upstream of Lake Oroville. The potential influence on the nutrient transfer may contribute to a general decrease in productivity in the aquatic and terrestrial ecosystems of the upstream tributary basins. For example, results of water quality tests in the North, Middle and South Forks of the Feather River indicate relatively low levels of limiting nutrients such as phosphates and nitrates (DWR 2001). However, focused studies on the Feather River investigating the relationship between blockage of anadromous salmonid passage and nutrient and organic material levels in the upstream tributaries have never been conducted.

The scope includes Lake Oroville because of the potential for partial compensation of lost energy and nutrients that may result from fish migrating from the reservoir and from consumption of fish in the reservoir by terrestrial species, and because of potential impacts on water quality and fish production and fish diseases of the reservoir if PM&Es are implemented to increase productivity of the upper basin streams.

The potential loss of ecological productivity due to the elimination of the anadromous chinook salmon and steelhead runs from the Feather River Basin upstream of Oroville Dam represents a continuing impact of the project on the biological resources of the area. Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the FERC Application for License for major hydropower projects, including a discussion of the fish, wildlife and botanical resources in the vicinity of the project. The discussion needs to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operation of the project. In addition to fulfilling these requirements, the specific investigations developed in this study plan will also be used in determining appropriate PM&E measures.

4.0 Study Area

Four major tributaries exist upstream of Lake Oroville including the North Fork Feather River, the West Branch of the North Fork Feather River, the Middle Fork Feather River, and the South Fork Feather River. The proposed study area is defined as the reaches of these tributaries existing between Lake Oroville's high water mark and the first salmonid migration barrier in each tributary. Previous investigations of tributary spawning potential have identified Miocene Dam on the West Branch of the North Fork Feather River, Curtain Falls on the Middle Fork Feather River, and Ponderosa Diversion Dam on the South Fork Feather River as impassable fish barriers, and Big Bend Dam on the North Fork Feather River as an impediment to upstream passage at all but the highest reservoir levels (DWR 1993). However, Task 1A of SP-F3.1 will provide the most current data regarding barriers to migrating salmonids in the tributaries upstream of Lake Oroville.

Smaller tributaries in the upstream drainages include Berry Creek, Canyon Creek, Chino Creek, Concow Creek, Fall River, French Creek, Frey Creek, Sucker Run Creek, McCabe Creek and Stony Creek. The portions of the smaller -order tributaries accessible to spawning salmonids will also be included in the analyses described in this study plan.

Study plans approved by the Environmental Work Group define the limits of the study area. If initial study results indicate that the study area should be expanded or contracted, the Environmental Work Group will discuss the basis for change and revise the study area as appropriate.

5.0 General Approach

This section describes the methods and tasks proposed to implement this study plan. This study is designed primarily as a desktop investigation to assemble and summarize information regarding historical escapement levels of salmonids in the tributaries upstream of Lake Oroville, potential escapement given the current habitat conditions in the upstream tributaries, the nutrient and organic matter levels derived from the salmonid escapement, and the nutrient mitigation alternatives, results, and potential implementation issues. At this time, a field study component is not necessary to fulfill the study objectives, however field data will be obtained from SP-F3.1 (habitat mapping of the tributaries upstream of Lake Oroville) and SP-F10 (spawning densities downstream of Lake Oroville). The study plan is structured as a three-task study. If initial study results indicate that the methods and tasks should be modified, the Environmental Work Group will discuss the basis for change and revise the study plans as appropriate.

~~This study~~In Task 1, a literature review will be conducted in two phases. ~~Phase 1 primarily will be a desktop study that will: 1) to estimate the potential loss-historical escapement of biomass-salmonids into the upper basin resulting from the elimination-reaches of the anadromous fish migrations and 2) assess effects of potential changes in nutrient loadings of the upper basin streams on their ecology and the ecology of Lake Oroville. Reviewers of this study plan have suggested several approaches for estimating the loss of fish biomass. One approach would use existing information such as agency reports and interviews and old newspaper articles to estimate the size of the runs that historically visited the upper basin stream reaches. For example, the run-size estimates included in the introduction of this study plan were obtained from a 1960 DFG memo. A second approach would use recent estimates from chinook salmon and steelhead spawning escapement surveys and estimates of the proportion of the returning fish that would have spawned in the accessible stream reaches upstream of Lake Oroville. However, sizes of the chinook salmon and steelhead runs since the construction of the project have been greatly influenced by Feather River Hatchery production. The hatchery is part of the Oroville Facilities and would probably not exist if Oroville Dam did not exist. The third approach would use estimates of currently available spawning habitat for chinook salmon and steelhead in the accessible stream reaches upstream of the reservoir to estimate the fish biomass. This approach will be adopted for this study because it is more straightforward than the other approaches.~~Feather River upstream of the existing Oroville Facilities. In Task 2, habitat mapping information (obtained from SP-F3.1) and spawning density calculations (obtained from SP-F10) will be utilized to determine an estimated potential maximum level of escapement into the upstream tributaries, assuming full habitat utilization. Task 3 will provide a literature review and summary of the types and amounts of nutrients and organic matter derived from salmonid

carcasses and spawning byproducts and the results of and potential issues associated with other nutrient transfer mitigation plans/strategies.

Estimates of the spawning habitat areas will be obtained by reviewing existing information including reports, scientific papers, surveys by DWR and other agencies, photographs and maps. This information will be obtained from study plan SP-F15, *Evaluation of the Feasibility to Provide Passage for Anadromous Salmonids Past Oroville Facility Dams*. Existing information also will be used to estimate the biomass of fish per unit measure of suitable spawning habitat. If the results of Phase 1 indicate that the losses of fish biomass to the upper basin are potentially large enough to significantly affect the nutrient and energy conditions in the upper basin, then Phase 2 will be implemented.

The study plan is organized into the following three tasks:

Several criteria may be used to judge the significance to the ecology of the basin's streams and Lake Oroville of the estimated losses of fish biomass and associated energy and nutrients. The criteria would likely be based on one or more of the following: 1) compare current concentrations of major nutrients in the streams and reservoir to estimates of potentially limiting concentrations from the scientific literature, 2) convert the fish biomass losses to rough estimates of nutrient losses and compare with current concentrations in the streams, and 3) estimate level of nitrogen enrichment in the streams from the reported general relationship between nitrogen enrichment of juvenile coho salmon and salmon carcass density (see below).

1. Document, review, and summarize the available literature regarding historical escapement of anadromous salmonids in the tributaries upstream of Lake Oroville;
2. Estimate the potential maximum escapement of salmonids given the existing habitat of the tributaries upstream of Lake Oroville;
3. Document, review, and summarize the existing literature regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning and the nutrient transfer mitigation plan methodologies, results, and potential implementation issues/strategies from other investigations.

Phase 2 will include desktop and field studies and will seek to answer two basic questions: (1) What is the net change in the amount of energy and nutrients available in the Feather River basin upstream of Lake Oroville resulting from the elimination of chinook salmon and steelhead runs upstream of the Fish Barrier Dam and (2) What effect has the change in the energy and nutrients had on the biological resources of the basin? Different approaches will be used for answering these two questions. The first question will be addressed using a quantitative modeling approach, while the second question will be addressed using a narrative approach based on a general understanding of the basin's ecology.

In order to achieve the final objective of collecting baseline information to serve as a foundation for the development and evaluation of potential future PM&Es, information from many sources must be integrated and summarized. The literature review may include, but is not limited to, the following existing sources:

- Annual population estimates for fall and spring run chinook salmon returning to spawn. Surveys conducted by DFG (using various methods) every fall since 1954
- Initial hatchery production goals from the annual reports from the Feather River Hatchery (Interim) Facility, CDFG, Inland Fish Administration.
- DFG. 1952. Fisheries problems of the Feather River with special reference to the proposed Oroville Dam. October 30, 1952.

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 - Wooster, T. W. 1966. A report to the California State Water Rights Board on the fish and wildlife resources of the Feather River to be affected by the Oroville Dam and Reservoir, Thermalito Diversion, Thermalito Forebay, and Thermalito Afterbay and measures proposed to maintain these resources. California Department of Fish and Game, pg. 29.
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 - Michael, J.H., Jr. 1998. Pacific salmon escapement goals for the Skagit River watershed as determined by nutrient cycling considerations. Northwest Science 72:239-248.
 - Richey, J.E., M.A. Perkins, and C.R. Goldman. 1975. Effects of kokanee salmon (*Oncorhynchus nerka*) decomposition on the ecology of a subalpine stream. Journal of the Fisheries Research Board of Canada 32:817-820.
 - Schuldt, J.A. and A.E. Hershey. 1995. Effect of salmon carcass decomposition on Lake Superior tributary streams. Journal of the North American Benthological Society 14:259-268.
 - Concurrent studies occurring as part of the Oroville Facilities FERC relicensing process.

Detailed Methodology and Analysis Procedures

~~Phase 1 will include the following tasks:~~

- ~~Establish historic distributions of upstream chinook salmon and steelhead migrations;~~
- ~~Identify suitable chinook salmon and steelhead spawning habitat within stream reaches with historic runs upstream of Lake Oroville;~~
- Estimate potential biomass of chinook salmon and steelhead using currently available spawning habitat; and

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- ~~Conduct water quality sampling and preliminary nutrient analyses to assess potential significance of changing the nutrient conditions of the affected stream reaches.~~

Phase 2 will include the following tasks:

- ~~Develop conceptual framework for energy and nutrient changes in the basin; and~~
- ~~Evaluate the ecological impacts of changes in energy and nutrient conditions as a result of the loss of historic anadromous fish biomass.~~

Phase 1

Task 1—Determine Historic Distributions of Upstream Chinook Salmon and Steelhead Migrations

~~To determine the geographic scope of the effect of the historical chinook salmon and steelhead runs on the energy and nutrient status of the upper basin streams, the study plan will need to identify all stream channel obstructions that would have limited upstream migration of chinook salmon and steelhead prior to construction of Oroville Dam. The principal obstructions are generally known and may include Big Bend Dam and Poe Dam on the North Fork Feather River, Ponderosa Diversion Dam on the South Fork Feather River, and Curtain Falls on the Middle Fork Feather River. Big Bend Dam had a non-functional fish ladder (Taylor 2001). Reports and newspaper articles will be reviewed to estimate chinook salmon and steelhead passage over this dam. Maps and agency reports will be consulted to determine the probable upstream limits of migration on all the streams that are tributary to Lake Oroville. If necessary, field surveys of obstructions will also be conducted. Only obstructions likely to have been established before Oroville Dam was constructed would be included in the assessment of the historical upstream migration limits. The information necessary to complete this task will be obtained from study plans SP-F3.1, *Evaluation of Project Effects on Resident Fish and Their Habitat within Lake Oroville, the Thermalito Complex and Upstream Areas within Project Boundaries* and SP-F4, *Passage of Resident Fish Upstream of Lake Oroville*.~~

Task 1—Document, review, and summarize the available literature regarding historical escapement of anadromous salmonids in the tributaries upstream of Lake Oroville

Task 1 will consist of a review and summary of the historical chinook salmon and steelhead escapement and spawning data available for the upstream tributaries of Lake Oroville. In order to estimate the number of anadromous salmon whose passage to upstream tributaries and subsequent nutrient transfer was blocked by the Oroville Facilities, historical escapement data collection will focus on the time period between 1944 (construction of the tributary dams) and 1963 (completion of the Oroville Facilities).

Task 2—Identify Suitable Chinook Salmon and Steelhead Spawning Habitat within Stream Reaches with Historic Runs Upstream of Lake Oroville

~~The information necessary to accomplish this subtask will be provided by study plans SP-F3.1, SP-F4, and SP-F15.~~

Agency reports and data relating to the escapement of salmonids from the tributaries upstream of Lake Oroville will be collected, reviewed, and summarized. The review will incorporate historical investigations by federal and state agencies, peer-reviewed literature focusing on the Feather River system, and creel census reports. A wealth of information may also be available within the reports and information which formed the basis of the mitigation programs relating to the Oroville facilities. Specifically, the escapement estimates from the upper tributaries used to develop the initial Feather River Hatchery production goals will be investigated.

Specific application of the information in this task includes:

Some of the data collected before the construction of the Oroville Facilities may not be officially published in agency reports. Furthermore, because the time periods of concern for Task 1 extends to over 50 years ago, some agency reports and data may have been transferred to a storage facility. For these reasons, natural resource professionals at various agencies may be asked to scour their files, specifically attempting to identify all reports, data, or otherwise useful information which may be available in their offices. Interviews with long-time or retired agency personnel may also prove useful in locating agency reports and data, as well as provide anecdotal observational information regarding the upper tributaries of the Feather River. In addition to agency resources, regional newspaper articles may provide estimates of historical escapement. Interviews with private parties in the Central Valley, particularly local sportfishing guides, recreational fishing clubs, and long-time area residents may also aid in approximating the historical escapement levels. Additionally, oral interviews with elders and other knowledgeable members of the Native American community will be conducted as directed by SP-C1 and testimony regarding the historical escapement of anadromous salmonids will be incorporated when possible.

- ~~• Identification and mapping of the streams and creeks that constitute the watershed of the West Branch and the North, Middle and South forks of the Feather River, using 7.5 minute quadrangle U.S. Geological Survey (USGS) topographic maps (it is anticipated that the mapping effort and resources will be developed and provided through coordination of the geomorphology study plan efforts and GIS work group);~~
- ~~• Review of available historic and recent aerial photographs and topographic maps of the upper basin streams to identify potential salmonid spawning grounds;~~
- ~~• Review of existing water quality, sediment and riparian vegetation information for the upper basin streams (to be obtained in coordination with other environmental study plans, including water quality, geomorphology, and terrestrial disciplines);~~
- ~~• Review of data and reports from upper basin stream surveys performed by federal and state agencies, as well as private parties, to locate or assess salmonid spawning habitat; and~~
- ~~• Review of data and reports from upper basin stream surveys performed by federal and state agencies, as well as private parties, to identify seasonal temperature and flow conditions.~~

To adequately assess the historical escapement to the North Fork Feather River, a literature review will be conducted regarding the effectiveness of the Big Bend Dam fish ladder. Any information pertaining to the functionality of Big Bend Dam fish ladder prior to the construction of the Oroville Facilities will be reviewed and summarized. The historical escapement estimations may be corrected, if necessary, to reflect these findings.

~~Task 3—Estimate Potential Biomass of Chinook Salmon and Steelhead Using Available Spawning Habitat~~

Existing information on biomass of spawning salmon and steelhead per area or length of suitable spawning habitat will be used to convert estimates of suitable spawning habitat in the upper basin stream reaches to estimates of fish biomass. To the extent possible, biomass information from streams that have fall-run and spring-run chinook salmon and steelhead runs and that are similar in size and other characteristics to the upper basin streams will be used. The required information will be sought from reports of resource agency surveys and independent scientific research.

The results of these investigations will be summarized and a range of historical escapement values will be developed. In Task 3 of this study plan, the escapement information will be converted to a range of nutrient

delivery values, which will approximate the levels of nutrients and organic material historically delivered to the upper tributaries.

~~Task 4—Conduct Water Quality Sampling and Preliminary Nutrient Analyses to Assess Potential Significance of Changing Nutrient Concentrations in the Upper Feather River Basin Streams~~

~~This task will assess the effects of reductions in nutrients, if any have occurred, on the upper basin stream reaches. The assessment will help to determine the ecological significance of a loss of nutrients and how enhancement measures to increase these nutrients would affect the stream and reservoir ecosystems. For example, the results could indicate that these nutrients do not limit stream production at the times of year when the chinook salmon and steelhead runs historically affected the streams and, therefore, a reduction in the level of the nutrients with the elimination of the runs probably would have had no effect on production. Augmenting nutrients under such conditions could lead to undesirable eutrophication of the streams and reservoir.~~

Task 2— Estimate the potential maximum escapement of salmonids given the existing habitat of the tributaries upstream of Lake Oroville

Task 2 will evaluate the potential for spawning of chinook salmon in the upstream tributaries. Essentially, Task 2 will provide an escapement estimate which assumes that the Oroville Facilities did not block the passage of spawning anadromous salmonids into the upstream tributaries. The estimated escapement of chinook salmon will be calculated using information collected in SP-F3.1 and SP-F10.

~~Much of the information necessary to accomplish this task will be provided by SP-W1, *Project Effects on Water Quality Designated Beneficial Uses for Surface Waters*. Specific application of this task includes collection of water samples from Lake Oroville and the tributary streams historically visited by chinook salmon and steelhead runs, and analysis of the samples for nitrogen and phosphorous levels. Standard United States Environmental Protection Agency (EPA) methods will be used to measure nitrogen and phosphorous concentrations. Results of the analyses will be used to assess potential effects of increased nutrients in the streams and the reservoir.~~

Task 1C of SP-F3.1 will identify available chinook spawning habitat in the upstream tributaries from the Lake Oroville high water mark to the first upstream migration barrier. GIS coverages of habitat components will be developed to estimate the location, extent and relative qualities of habitat. Suitable spawning habitat locations will be determined by combining the habitat component coverages to identify areas with the combinations of habitat characteristics that fit the profile of chinook salmon spawning habitat preferences. Habitat components will be combined from other study plans to identify suitable habitat including:

~~The potential significance of the losses of fish biomass on the streams' nutrient levels will also be assessed by means of simple analyses. One analysis will employ estimates of the nitrogen and phosphorus content of salmon carcasses (Larkin and Slaney 1997) and information on hydrology to convert the lost fish biomass estimates to estimates of nitrogen and phosphorus loading. These estimates will be compared to the estimates of current nitrogen and phosphorous concentrations. Another analysis will employ a general statistical relationship between the biomass density of salmon carcasses in streams and an index of marine nitrogen enrichment of juvenile salmon in those streams (Bilby et al. 2001) to evaluate the significance of lost fish biomass on nutrient conditions of the upper basin streams. The results of the water quality sampling and the nutrient analyses will be used in a technical review of Phase 1 to decide whether or not to proceed with Phase 2 of the study.~~

- mesohabitat maps provided by SP-G1;
- substrate characterization, transect data, channel morphology, assessment of woody debris, and cover cross-sectional monitoring data including water depth, velocity, and turbidity obtained from SP-G1;
- inundation flow boundaries at various flow levels interpolated from SP-G1 channel transects;
- vegetation survey results (grass, shrub, bush, tree classes) obtained from SP-T4;
- water temperature data obtained from SP-W6;
- water quality data obtained from SP-W1;
- exceedances of water quality recommendations for freshwater aquatic life obtained from SP-W1.

Phase 2

Task 1—Develop Conceptual Framework for Energy and Nutrient Changes in the Basin

~~A conceptual framework for energy and nutrient changes in the basin will be used to identify information needs, organize the information obtained and guide the analyses. The framework for estimating energy and nutrient changes in the basin will include the system inflows, outflows and processes described below. GIS coverages will be constructed to illustrate the areas which provide suitable habitat for chinook salmon by applying superimposing the habitat requirement characteristics over against the existing habitat condition attributes. A total estimated area of suitable chinook salmon spawning habitat will be calculated by summing all of the areas which meet the predetermined spawning habitat criteria.~~

- ~~Total biomass of fish that would migrate upstream of Oroville Dam site each month, if the dam were absent (would use Phase 1 results and run timing information from SP-F10, *Project Effects on Anadromous Fish and Their Habitat*).~~
- ~~Final distribution of the fish biomass in the upper Feather River and tributaries (note that most of the biomass, particularly of fall run chinook salmon, which typically have more abbreviated migrations than spring-run chinook, would have remained in the stream channels currently inundated by the reservoir and would therefore have no effect on the current upper basin resources) (would use Phase 1 results).~~
- ~~Energy densities (e.g., calories per gram of fish) and nutrient concentrations (e.g., milligrams of nitrogen or phosphorous per gram of fish) in adult salmon and steelhead tissues, eggs and metabolic products.~~
- ~~Fate of energy and nutrients contained in fish biomass (amount to eggs and milk, amount excreted, amount remaining in the small percentage of adult fish that return to ocean, amount in carcasses consumed by other fish [including juvenile salmon and steelhead], amount consumed by aquatic invertebrates, amount consumed by terrestrial invertebrates, amount consumed by wildlife species, amount absorbed by algae and other plants, amount flushed out of system).~~
- ~~Water temperatures and flows in streams when energy and nutrients from migrating fish are most available (water temperatures drive metabolic processes that cycle energy and nutrients through the system, and flows affect retention of the energy and nutrients in the system, therefore, fish biomass arriving to the streams during summer months would likely be more completely used than biomass arriving during winter months) (would partially use information from SP-W1, *Project Effects on Water Quality Designated Beneficial Uses for Surface Waters*, for water temperatures and project studies of hydrology, for flows).~~

- Life history cycles of aquatic and terrestrial species that would exploit energy and nutrients made available by migrating chinook salmon and steelhead (the life cycles would influence how the salmon and steelhead were utilized each month).
- Mortality of juvenile chinook salmon and steelhead and biomass of smolts that would exit the upper basin streams each month were the chinook salmon and steelhead runs continuing (would use information from SP-F10, *Project Effects on Anadromous Fish and their Habitat*, for run timing).
- Energy density and nutrient concentrations of chinook salmon and steelhead smolts.
- Biomass of fish currently migrating each month from Lake Oroville into the upper basin streams (if available, would use information obtained from field studies for SP-F3.1).
- Biomass of living and dead fish in Lake Oroville consumed by terrestrial species (birds and mammals).
- Energy densities and nutrient concentrations and fate of energy and nutrients (eggs, carcasses, return to lake, consumed, etc.) of fish that currently migrate from the reservoir and of fish removed from the reservoir by terrestrial species.

Task 2B of SP-F10 will provide spawning density estimates for chinook salmon in the Feather River downstream of Lake Oroville. Because a majority of the chinook salmon spawning in the Feather River occurs between the Fish Barrier Dam and the Thermalito Afterbay Outlet, this task will capture the spawning densities from the surveys focused between these locations. Escapement of naturally spawned chinook salmon will be estimated using carcass mark-recapture procedures outlined in Taylor (1974). The sizes of each riffle section where carcasses have been observed in the course of each sampling week will be calculated by estimating the spawning area from aerial photographs or by real-time kinematic (RTK) GPS survey of the spawning area boundaries. ~~The calculated riffle sizes will be added to produce estimates of weekly or monthly spawning areas in the reach extending from the Fish Barrier Dam to the Thermalito Afterbay River Outlet.~~ The spawning densities will then be calculated by determining the number of spawned chinook salmon (estimated in the carcass survey) per unit area of adjacent riffles.

For the most part, existing information will be used to estimate values for the parameters listed above.

Anticipated information sources include, but are not limited to, the following:

~~The potential maximum escapement of chinook salmon into the upper tributaries will be approximated as the product of the spawning habitat availability in the upstream tributaries (SP-F3.1) and the spawning adult utilization per unit of available habitat in the Feather River downstream of the Oroville Facilities (SP-F10). Spawning density averages of other river systems from a literature review will also be calculated to estimate an average spawning density utilization. This method of escapement calculation assumes fullfull utilization at a range of spawning densities of the available habitat of the upstream tributaries .by adult salmonids and equivalent spawning densities between potential chinook salmon populations upstream and existing spawning populations downstream of Lake Oroville. While the escapement number derived in this fashion will be a rough estimate, it will allow for the development of a baseline reference from which to evaluate potential future PM&Es.~~

- Results of scientific studies of chinook salmon and steelhead egg, juvenile and smolt survival will be used to derive estimates of biomass of chinook salmon and steelhead smolts produced per adult fish;
- Scientific fisheries articles will be searched to obtain estimates of energy density and nutrient concentrations of chinook salmon and steelhead and to estimate the fate in the ecosystem of the energy and nutrients released from the adult salmonid population. Recent review articles in *Fisheries* magazine provide many useful references;

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- ~~Resource agency documents and fishing reports will be examined and interviews with agency staff and local fishing experts will be conducted to develop estimates of run sizes for any Lake Oroville fish species that currently migrate into tributary streams; and~~
 - ~~A search of the literature will be conducted to estimate the amount of feeding by terrestrial species on chinook salmon and steelhead and their eggs and carcasses that would likely have occurred prior to the elimination of the chinook salmon and steelhead runs, as well as that currently likely to occur on living and dead fish in Lake Oroville. The search will focus on reports from river basins with chinook salmon and steelhead runs and terrestrial species similar to those of the Feather River basin.~~

~~Although Task 1C of SP-F3.1 will only provide habitat data for the upstream tributaries above Lake Oroville's high water mark, an estimate of the escapement potential for the water fluctuation and permanent inundation zones of Lake Oroville will also be calculated. These estimates will be interpolated as the product of the estimated escapement of anadromous salmonids per river mile in the upstream tributaries and the length of the historic river channel within the water fluctuation and permanent inundation zones. The escapement potential of these zones will not only allow for a straightforward comparison between the escapement estimates provided by Task 1 and 2, but may also prove useful when designing potential PM&Es. If similar interpolations are required for tributary reaches above the identified upstream migration barrier (Task 1A of SP-F3.1), such calculations will be made under the cumulative analysis (SP-F12).~~

~~As necessary, the existing information and information from other study plans will be supplemented with field studies. In particular, count surveys of migrating fish and fish carcasses may be required to estimate the biomass of fish that currently migrate from Lake Oroville to tributary streams and observations of wildlife species may be needed to estimate feeding of terrestrial species on live and dead fish in the upper stream reaches and the lake.~~

~~Task 3— Document, review, and summarize the existing literature regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning and the nutrient transfer strategies from other investigations. regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning and the nutrient transfer mitigation plan methodologies, results, and potential implementation issues from other investigations.~~

~~Task 3 will supply two types of information to this study plan. First, Task 3 will investigate the types and amounts of nutrients and organic matter provided by the decomposition of salmonid carcasses and other spawning byproducts. Second, Task 3 will review and summarize the mitigation plan methodologies, results of nutrient mitigation programs, results of monitoring programs, and issues associated with mitigation implementation from other investigations.~~

~~Task 2— Evaluate the Ecological Impacts of Changes in Energy and Nutrient Conditions Resulting from the Loss of Historic Anadromous Fish Biomass in the Basin~~

~~This task will integrate conclusions regarding changes in energy and nutrients with information on current conditions in the basin to assess the effects of the loss of historic anadromous fish biomass on the aquatic and terrestrial biological resources of the upper basin. Conclusions from the conceptual framework on energy and nutrients will be used to estimate how the loss of fish biomass has affected energy and nutrient cycling in the upper basin stream and terrestrial ecosystems. This information will be evaluated in the context of current ecological conditions to assess the impacts of changes in energy and nutrients on the basin's~~

~~aquatic and terrestrial resources. It is anticipated that much of the information on the effects of changes in nutrients would be obtained from results of Task 4 in Phase 1 of the study, but additional water quality sampling for nutrients might be required. Other sampling and analysis may be necessary to determine current limiting factors of biological populations in the basin and to assess how changes in energy and nutrients conditions would affect these factors.~~

~~Published literature regarding the types and amounts of nutrients and organic matter derived from salmonid carcasses and spawning byproducts will be collected, reviewed, and summarized. While some information may be found in federal and state agency reports, a majority of the necessary information will likely be obtained through a peer-reviewed literature search. The results of the summary will likely identify a range of characteristic properties of salmonid-derived nutrients. A matrix will be constructed which will include the types of salmonid-derived nutrients and the range of amounts of each type of nutrient supplied per unit of salmonid biomass. The matrix will be used to determine the amount of each nutrient type that was or could be supplied by the escapement levels estimated in Tasks 1 and 2. In this manner, total nutrient and organic matter totals for the upstream tributaries will be estimated. This information will serve as a benchmark for development and evaluation of potential future PM&Es.~~

~~Task 3 will also identify the nutrient transfer strategies from other investigations, including mitigation methodologies, results of mitigation and monitoring programs, and the potential issues associated with nutrient replacement mitigation from other projects transfer strategies. Many of the mitigation examples of nutrient transfer strategies are expected to be supplied from studies within the Pacific Northwest, although special effort will be given to identifying mitigation examples from the Central Valley and other parts of California. The mitigation nutrient transfer plans strategies will be reviewed and summarized, specifically relaying the various methodologies utilized by past projects, and the results of each restoration technique. The summaries will provide useful information when identifying the potential to conduct PM&Es in the upper tributaries.~~

6.0 Results and Products/Deliverables

Results

~~The results for Phase 1 will provide an assessment of the amount of anadromous fish biomass in the upper Feather River basin stream reaches lost as a result of construction of the Oroville Facilities and of the ecological significance of changing nutrient concentrations in these streams. Phase 2, which will be implemented only if the results of Phase 1 indicate that the loss of biomass is potentially significant, will quantify the net changes of energy and nutrients to the streams and will assess the ecological impacts of the changes. The net changes will be determined as the balance of losses resulting from the elimination of anadromous fishes and gains resulting from migrations and terrestrial consumption of fish produced in Lake Oroville.~~

Phase 1 Results

~~Results for each task will be presented in a Summary Report that will include a narrative as well as tables, figures and maps summarizing results.~~

~~The Summary Reports will provide the following:~~

~~Results will be organized following the task headings. Each task will include a narrative summary of the relevant literature review and findings as well as tables, figures and maps summarizing the key points. The results of the three sections will be integrated to provide the tools needed to develop and evaluate potential future PM&Es relating to the upstream transfer of nutrients to ecosystems upstream of Lake Oroville. The anticipated maps, graphical representation of reviewed data (e.g., charts, and graphs) and summary figures and tables include:~~

~~•*Historic Distribution of Upstream Chinook Salmon and Steelhead Migrations*, will include a full discussion of all the sources of information, including assessments of their reliability. The principal product will be a map showing the distribution of the different chinook salmon and steelhead runs in the upper basin streams and identifying all obstructions that would have limited upstream migration. It is anticipated that most of this information will be provided by studies SP-F3.1 and SP-F4.~~

~~•*Suitable Chinook Salmon and Steelhead Spawning Habitat within Stream Reaches with Historic Runs Upstream of Lake Oroville*, will include a full description of all sources of information and will provide assessments of the reliability of the information. Summary tables will describe the quantity and quality of existing habitats for anadromous salmonid spawning and the location of these habitats will be shown on maps. It is anticipated that most of this information will be provided by studies SP-F3.1, SP-F4 and SP-F15.~~

- ~~• Narrative summary and appropriate graphics and tables from historical (1944-1963) escapement reports including technical agency documents, unpublished agency data, newspaper articles, and interviews with sporting clubs, agency personnel, and long-time area residents (Task 1);~~
- ~~• Figures, tables, calculations, assumptions, and narratives summarizing the results of the escapement estimate derived from the integration of current habitat availability in the upstream tributaries and current spawning densities in the Feather River downstream of the Oroville Facilities (Task 2);~~
- ~~• Figures, tables, calculations, assumptions, and narratives summarizing the results and methods of the conversion of the escapement estimates (provided in Tasks 1 and 2) to the total salmonid-derived nutrient and organic matter which was/could be supplied to the upstream tributaries (Task 3);~~
- ~~• Narrative summary and appropriate graphics and tables relating to the methods, results, and potential issues associated with the nutrient mitigation measures attempted in the Central Valley, California, and the Pacific Northwest (Task 3).~~

Products/Deliverables

The study plan summary report will include:

~~•*Estimate Potential Biomass of Chinook Salmon and Steelhead Utilizing Available Spawning Habitat*, will include a full description of all sources of information and will provide assessments of the reliability of the information. Tables will list estimates of chinook salmon and steelhead biomass per area or length of spawning habitat obtained from the literature review. Final estimates of biomass for each chinook salmon and steelhead run will be presented. A discussion of the computations used to derive these estimates will be presented, including the assumptions used in the computations and their validity.~~

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- ~~Conduct Water Quality Sampling to Assess Potential Significance of Adding Nutrients to the Upper Feather River Basin Streams~~, will provide a description of sampling protocols and methods and analytical procedures, including detection limits. All or part of this information may be obtained from study SP-W1, *Project Effects on Water Quality Designated Beneficial Uses for Surface Waters*. Results will be provided in tabular form. Potential nutrient limitation and/or eutrophication will be discussed. The results of the preliminary nutrients analyses and conclusions regarding ecological significance will be provided.

Phase 2 Results

Assuming the Environmental Work Group decides to implement Phase 2, the results will be provided as follows in a Summary Report for each task:

- Executive Summary
- Table of Contents
- List of Tables
- List of Figures
- Introduction
- Methodology
- Narratives of relevant findings by task
- Discussion addressing most relevant questions (see above) and indicating any complications/data concerns
- Conclusions related to study plan goals and objectives
- References
- Appendices

7.0 Coordination and Implementation Strategy

Coordination with Other Resource Areas/Studies

It is anticipated that this study will require coordination with those individuals responsible for collecting the field data associated with the upstream tributaries spawning habitat mapping and the spawning densities of chinook salmon from the Feather River downstream of the Oroville Facilities.

- ~~Develop Conceptual Framework for Energy and Nutrient Changes in the Basin~~, will include a full description of all sources of information and will provide assessments of the reliability of the information. Much of the information will necessarily be obtained from studies of runs of different salmon species and ecosystems with very different characteristics than those of the Feather River basin. The significance of such differences will be carefully examined and discussed. The principal product provided in the Summary Report for this task will be a flow chart that describes the conceptual framework. A discussion of the framework will provide the principal conclusions and will identify major weaknesses of the framework and where additional information would be most useful. If field work is required to estimate effects on the energy and nutrient status of the streams and terrestrial ecosystems resulting from spawning migrations of fish from the reservoir to the streams or from consumption of reservoir fish by terrestrial species, the report will provide a description of sampling protocols and methods and analytical procedures employed. Results of field studies will be presented in tables of raw data and derived

~~estimates of biomass, energy and nutrients, including statistical measures of precision. The field work may not be necessary as much of the information on current biomass of spawning fish in the upper basin stream reaches may be provided by other studies (i.e., SP-F3.1).~~

- ~~• Evaluate the Ecological Impacts of Changes in Energy and Nutrient Conditions Resulting from the Loss of Historic Anadromous Fish Biomass in the Basin, will provide a discussion of the ecological impacts of changes in energy and nutrient conditions in the basin and an assessment of effects of PM&E measures to augment energy and nutrient loading. If additional work is required to estimate limiting factors of fish and wildlife populations, the report will provide a description of sampling methods and analytical procedures employed.~~

Products/Deliverables

~~The results of Phase 1 of this study plan will be presented in a report that synthesizes the results of the phase's four tasks. The report will present final conclusions regarding the amount of fish biomass lost as a result of the Oroville Facilities and the potential significance of this loss. Based on the findings of Phase 1, a determination will be made by the Environmental Work Group whether it is appropriate to pursue Phase 2 of the study plan. If Phase 2 is implemented, the results will be presented in a comprehensive report synthesizing all of the study results and presenting final conclusions regarding the effects of eliminating the chinook salmon and steelhead runs from the upper basin stream reaches. The study results will be used to assess the desirability for PM&E measures. If PM&E measures are required, the results will help to guide the selection of appropriate measures and to evaluate any potential adverse impacts.~~

~~Given the nature of the tasks of this study, contacts with work groups directing and conducting other studies relevant to the Oroville Facilities FERC Relicensing Project are also expected. A list of study plans that will be related to the development of the present study includes:~~

- ~~• SP-F3.1 Evaluation of Project Effects on Resident Fish and their Habitat within Lake Oroville, its upstream tributaries, the Thermalito Complex, and the Oroville Wildlife Area~~

7.0 Coordination and Implementation Strategy

Coordination with Other Resource Areas/Studies

~~This study and possible PM&Es developed as a result of the study may require coordination with the study plans listed and described below.~~

~~Task 1A of SP-F3.1 will identify the migratory barriers in the upper tributaries to be used to define the study area of this study plan. Task 1C of SP-F3.1 will identify the available chinook spawning habitat to be used in estimating the escapement potential for the upstream tributaries in Task 2 of this study plan. Suitable spawning habitat locations will be determined by combining the GIS habitat component coverages to identify areas with combinations of habitat characteristics that fit the profile of chinook salmon habitat preferences. Habitat components will be combined from other study plans to identify suitable habitat including:~~

- ~~• mesohabitat maps provided by SP-G1;~~

- substrate characterization, transect data, channel morphology, assessment of woody debris, and cover cross-sectional monitoring data including water depth, velocity, and turbidity obtained from SP-G1;
- inundation flow boundaries at various flow levels interpolated from SP-G1 channel transects;
- vegetation survey results (grass, shrub, bush, tree classes) obtained from SP-T4;
- water temperature data obtained from SP-W6;
- water quality data obtained from SP-W1;
- exceedances of water quality recommendations for freshwater aquatic life obtained from SP-W1.

SP-W1—Project Effects on Water Quality Designated Beneficial Uses for Surface Waters

This study, which will evaluate the effects of existing and future water projects and facilities on all designated beneficial uses of water, will include sampling for nitrogen, phosphorous and other water quality parameters at a number of locations in stream reaches above Lake Oroville.

GIS coverages will be constructed to illustrate the areas which provide suitable habitat for chinook salmon by superimposing the habitat requirement coverages over the existing habitat conditions. A total estimated area of suitable chinook salmon habitat will be calculated by summing all of the areas which meet the predetermined habitat criteria.

SP-W3—Recreational Facilities and Operations Effects on Water Quality

Effects of existing and future project operations on the physical, chemical and biological components of water quality of the Feather River, affected tributaries, and downstream waters.

- SP-F10 Project Effects on Anadromous Salmonids and their Habitat

SP-F3.134Evaluation of Project Effects on Resident Fish and Their Habitat within Lake Oroville, the Thermalito Complex and Upstream Areas within Project Boundaries

This study plan will provide information that characterizes existing fish habitat conditions of Lake Oroville and its four primary tributaries, including the North, Middle and South Forks of the Feather River and the West Branch Feather River.

Task 2B of SP-F10 will provide spawning density estimates for chinook salmon in the Feather River downstream of Lake Oroville to be used in estimating the escapement potential in the upstream tributaries in Task 2 of this study plan. Escapement of naturally spawned chinook salmon will be estimated using carcass mark-recapture procedures outlined in Taylor (1974). The sizes of each riffle section where carcasses have been observed in the course of each sampling week will be calculated by estimation of spawning area from aerial photographs or by real-time kinematic (RTK) GPS survey of the spawning area boundaries. The calculated riffle sizes will be added to produce estimates of weekly or monthly spawning areas in the reach extending from the Fish Barrier Dam to the Thermalito Afterbay River Outlet. The spawning densities will then be calculated by determining the number of spawned chinook salmon (estimated in the carcass survey) per unit area of adjacent riffles.

- Oral history from SP-C1-Cultural Resources Inventory

SP-C1 will provide results of oral interviews with elders and other knowledgeable members of the Native American community regarding cultural and historical resources. Relevant information from oral interviews regarding the historical escapement of anadromous salmonids will be incorporated into SP-F8.

SP-F4~~3~~4 Evaluation of Project Effects on Resident Fish Passage Upstream of Lake Oroville

~~SP-F4 will provide information on the current upstream migratory barriers in the four primary tributaries to Lake Oroville.~~

~~SP-F10³⁴Project Effects on Anadromous Fish and their Habitat~~

The Feather River anadromous salmonid life history and habitat requirements information compiled for the SP-F10 study plan will be referenced for this study. Graphical representations of the lifestage periodicity also will be obtained from SP-F10 for these species. This will include information on the quantity and quality of existing upstream habitat conditions and potential sources of mortality for anadromous salmonid spawning, rearing, and juvenile emigration.

~~SP-F15³⁴Evaluation of the Feasibility to Provide Passage for Anadromous Salmonids Past Oroville Facility Dams~~

SP-F15 will compile information from other fisheries study plans that summarizes the locations, quantity and quality of existing habitats for anadromous salmonid spawning. This information will be utilized under Phase 1, Task 2.

~~Terrestrial Resource Study Plans~~

Coordination with wildlife biology surveys also will be required to assess the amount of feeding by terrestrial species on fish in the streams and the lake.

~~Hydrology Study Plans~~

Coordination with hydrology studies will be required for information on the distribution by year type of daily median flows in the Upper Feather River and tributaries.

Issues, Concerns, Comment Tracking and/or Compliance Requirements

**Stakeholder Issues ~~Statements Fully~~ Addressed by the Transfer of Energy and Nutrients
by Anadromous Fish Migrations Study Plan**

Issue	Description
FE29	Protection of upstream resources energy balance issues—historic uses salmon-steelhead moving upstream—biomass—nutrient dispersal.
FE82	Prior to construction of Oroville Dam anadromous fish had access to the POE reach of the North Fork Feather River. These fish provided a source of energy to the river ecosystem. Construction of the dam severed that connection. There is an interest in determining the contribution of anadromous fish as an energy source for aquatic dependent species located in the North Fork Feather River and devising a strategy for replacing this loss.

Source: National Environmental Policy Act (NEPA) Scoping Document 1 and California Environmental Quality Act (CEQA) Notice of Preparation. DWR 2001.

8.0 Study Schedule

It is anticipated that the Phase 1 Final Summary Report will be completed by December 2002. The Phase 2 Summary Report, if needed, will be completed by December 2003.

Timing/Deadlines			
Task	Data collection/analysis occurring in SP-F8	Interim Report	Final Report
1	Document, review, and summarize the available literature regarding historical escapement of anadromous salmonids into the tributaries upstream of Lake Oroville		
2	Estimate the potential maximum escapement of chinook salmon given the existing habitat of the tributaries upstream of Lake Oroville	N/A	To be complete within three months after the necessary data from SP-3.1 and SP-F10 become available
3	Document, review, and summarize the existing literature regarding the types and amounts of nutrients and organic matter supplied by salmonid spawning		
	Document, review, and summarize the nutrient transfer mitigation plans, results, and potential implementation issues/strategies from other investigations		

9.0 References

Bilby, R.E., B.R. Fransen, J.K. Walter, C.J. Cederholm and W.J. Scarlett. 2001. Preliminary Evaluation of the Use of Nitrogen Stable Isotopes to Establish Escapement Levels for Pacific Salmon.—In addition to the references cited in Section 5.0, a complete list of references used in the completion of the study will be part of the summary report. The references cited in the present plan are listed below.

Bilby, R. E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries 26: 6-14, and Aquatic Sciences 53:64-73.

Cederholm, C. J., M.D. Kunze, T. Murota, and A. Sibitani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24(10):6-15.

DWR Environmental Services Office. October 1993. Lake Oroville Fisheries Management Plan. Progress Report.

DWR. 2001. Initial Information Package, Relicensing of the Oroville Facilities, January 2001.

~~Cederholm, C. Gresh, T., J., M.D. Kunze, T. Murota Lichatowich, and A. Sibatani. 1999. Pacific Salmon Carcasses: Essential Contributions of Nutrients and Energy for Aquatic and Terrestrial Ecosystems. P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries 24: 6-25(1): 15-21.~~

~~DWR (Taylor, S. N. (ed.) 1974. King (chinook) salmon spawning stocks in California's Central Valley, 1973. California Department of Water Resources). 2001. Initial Information Package, Relicensing of the Oroville Facilities, Federal Energy Regulatory Commission License Project No. 2100. January 2001. Fish and Game, Rep. No 74-12, 32 pp.~~

~~Gesh, T., J. Lichatowich, and P. Schoonmaker. 2000. An Estimation of Historic and Current Levels of Salmon Production in the Northeast Pacific Ecosystem. Fisheries 25: 15-21.~~
~~Larkin, G.A. and P.A. Slaney. 1997. Implications of trends in marine derived nutrients flow to south coastal British Columbia salmonid production. Fisheries 11: 16-24.~~